

Claims

- [c1] 1.A turbomachinery system for cooling a high power density device, comprising:
a turbomachine configured to deliver a high flux cooling medium, said
turbomachine having a motor and a compressor driven by said motor; and
at least one high power density device arranged in fluid communication with
said turbomachine.
- [c2] 2.The turbomachinery system of Claim 1, wherein the high flux cooling medium
is air.
- [c3] 3.The turbomachinery system of Claim 2, wherein said turbomachine has an air
mass-flow-to-flow-area ratio of equal to or greater than about 18 lbs/hr/sq-in
and equal to or less than about 144 lbs/hr/sq-in.
- [c4] 4.The turbomachinery system of Claim 3, wherein said turbomachine has an air
mass-flow-to-flow-area ratio of equal to or greater than about 54.5 lbs/hr/sq-
in and equal to or less than about 90.9 lbs/hr/sq-in.
- [c5] 5.The turbomachinery system of Claim 1, wherein the high flux cooling medium
is a refrigerant.
- [c6] 6.The turbomachinery system of Claim 2, wherein said turbomachine further
comprises:
a housing containing at least one of said motor and said compressor, said
housing providing a passage for air flow;
an inlet at a first end of said housing for accepting air flow; and
an outlet at a second end of said housing for discharging air flow.
- [c7] 7.The turbomachinery system of Claim 6, further comprising:
a heat exchanger thermally coupled to said at least one high power density
device; and
said turbomachine being downstream from said heat exchanger.
- [c8] 8.The turbomachinery system of Claim 7, wherein said heat exchanger
comprises:
a base for thermally coupling the heat exchanger to the high power density

device;

a plurality of parallel cooling fins arranged perpendicular to said base for receiving driven air at one end and discharging the driven air at the opposite end; and

a plurality of vortex chambers arranged between said cooling fins for creating a vortex like air flow as the air is driven between said cooling fins and through said vortex chamber, said plurality of vortex chambers having side walls integral with said plurality of parallel cooling fins.

- [c9] 9.The turbomachinery system of Claim 7, further comprising:
a transition duct arranged intermediate said heat exchanger and said inlet for funneling the air flow from said heat exchanger to said turbomachine.
- [c10] 10.The turbomachinery system of Claim 9, wherein said transition duct comprises:
a duct housing having a first end with a first flow area for receiving driven air from said heat exchanger having a plurality of cooling fins and a second end with a second flow area for discharging driven air to said turbomachine, said duct housing defining an internal cavity that transitions from said first flow area to said second flow area; and
a plurality of flow control fins within said internal cavity for managing the change in flow area from said first flow area to said second flow area.
- [c11] 11.The turbomachinery system of Claim 9, further comprising:
an expansion turbine driven by said motor and arranged proximate said outlet for expanding the high flux air flow as it is discharged from said turbomachine..
- [c12] 12.The turbomachinery system of Claim 9, further comprising a second turbomachine arranged for parallel air flow with said turbomachine, wherein said transition duct is arranged for funneling the air flow from said heat exchanger to said turbomachine and said second turbomachine in parallel.
- [c13] 13.The turbomachinery system of Claim 12, wherein the air flow from said heat exchanger to said turbomachine and said second turbomachine provides equivalent air flows through said turbomachine and said second turbomachine.

- [c14] 14.The turbomachinery system of Claim 9, wherein said at least one high power density device includes an integrated circuit.
- [c15] 15.The turbomachinery system of Claim 6, wherein said motor comprises magnetic bearings.
- [c16] 16.The turbomachinery system of Claim 1, wherein said compressor comprises at least one of an axial compressor and a centrifugal compressor.
- [c17] 17.The turbomachinery system of Claim 16, wherein said compressor comprises at least one of a single wheel compressor and a multi-wheel compressor.
- [c18] 18.The turbomachinery system of Claim 1, wherein said turbomachine has an overall dimension of no greater than 1.75 inches.
- [c19] 19.The turbomachinery system of Claim 1, wherein said turbomachine has an overall dimension suitable for 1U applications.
- [c20] 20.The turbomachinery system of Claim 9, wherein at least one of said heat exchanger and said transition duct has an acoustic damping structure comprising at least one material having an acoustic damping characteristic.
- [c21] 21.The turbomachinery system of Claim 20, wherein said acoustic damping structure comprises at least one of a porous surface and an acoustic damping bulk absorber.
- [c22] 22.The turbomachinery system of Claim 21, wherein said porous surface comprises at least one of a ceramic and a sintered metal, and said acoustic damping bulk absorber comprises at least one of a polymeric and a fiberglass material.
- [c23] 23.The turbomachinery system of Claim 6, wherein said outlet further comprises:
a nozzle outlet having secondary air ducts for entraining ambient air for providing a secondary cooling air flow.
- [c24] 24.The turbomachinery system of Claim 1, further comprising:
a soft starter for controlling start up of said turbomachine for preventing power

surges at said turbomachine during start up.

- [c25] 25.The turbomachinery system of Claim 7, further comprising:
an air particle ionizer arranged upstream of said heat exchanger for ionizing the
air particles prior to entering said heat exchanger and said turbomachine for
preventing particulate fouling of the turbomachinery system; and
an air particle de-ionizer arranged downstream of said outlet for neutralizing
the electrical charge of the discharging air particles.
- [c26] 26.The turbomachinery system of Claim 5, further comprising:
a closed-loop refrigeration circuit configured to cool said at least one high
power density device, the refrigerant flowing in said closed-loop refrigeration
circuit, said closed-loop refrigeration circuit comprising:
said compressor;
a condenser;
an expander;
an evaporator coupled to said at least one high power density device; and
a turbine driven by said motor.
- [c27] 27.The turbomachinery system of Claim 26, further comprising:
an ejector arranged for receiving and mixing the refrigerant at high pressure
from said compressor and the refrigerant at low pressure from said turbine, the
mixed refrigerant being delivered to said compressor for increasing the mass
flow through said compressor.
- [c28] 28.The turbomachinery system of Claim 27, further comprising:
a second turbomachine configured to deliver high flux air across said
evaporator to deliver cooled air to said at least one high power density device
and to deliver high flux air across said condenser to transport heated air to
ambient, said second turbomachine including a second motor, a fan driven by
said second motor and a housing for directing the flow path of the high flux air.
- [c29] 29.The turbomachinery system of Claim 26, wherein:
the refrigerant flows from said evaporator to said turbine, then to said motor,
and then to said compressor.

- [c30] 30.The turbomachinery system of Claim 26, wherein said expander comprises and expansion valve.
- [c31] 31.The turbomachinery system of Claim 30, wherein said expansion valve comprises and active expansion valve and said turbomachinery system further comprises:
an expansion valve control system for controlling the pressure drop of the refrigerant across said active expansion valve.
- [c32] 32.The turbomachinery system of Claim 29, wherein said compressor is a variable speed compressor.
- [c33] 33.A turbomachine for delivering a high flux cooling medium to a device, comprising:
a motor;
a compressor driven by said motor for compressing the high flux cooling medium;
a housing containing at least one of said motor and said compressor, said housing providing a passage for the high flux cooling medium;
an inlet at a first end of said housing for accepting the high flux cooling medium; and
an outlet at a second end of said housing for the discharging high flux cooling medium.
- [c34] 34.The turbomachine of Claim 33, wherein the cooling medium is at least one of air and a refrigerant.
- [c35] 35.The turbomachine of Claim 33, wherein said turbomachine has an overall dimension of no greater than 1.75 inches.
- [c36] 36.The turbomachine of Claim 33, wherein said turbomachine has an overall dimension suitable for 1U applications.
- [c37] 37.The turbomachine of Claim 33, wherein said motor comprises magnetic bearings.
- [c38] 38.The turbomachine of Claim 33, wherein said compressor comprises at least

one of an axial compressor and a centrifugal compressor.

- [c39] 39.The turbomachine of Claim 38, wherein said compressor comprises at least one of a single wheel compressor and a multi-wheel compressor.
- [c40] 40.An assembly comprising:
a mounting fixture; and
a plurality of turbomachinery systems of Claim 9 mounted adjacent one another within said mounting fixture.
- [c41] 41.An assembly comprising:
a mounting fixture; and
a plurality of turbomachinery systems of Claim 26 mounted adjacent one another within said mounting fixture.
- [c42] 42.A turbomachinery module for attaching to a surface and used for cooling high power density devices, comprising:
a module surface;
a turbomachine configured to deliver high flux air, said turbomachine including a motor, a compressor driven by said motor for compressing the high flux air, and a housing;
said housing containing at least one of said motor and said compressor and providing a passage for air flow;
said housing including an inlet at a first end for accepting air flow and an outlet at a second end for discharging air flow;
a heat exchanger for thermally coupling to and cooling a high power density device, said turbomachine being downstream from said heat exchanger; and a transition duct arranged intermediate said heat exchanger and said turbomachine for funneling the air flow from said heat exchanger to said turbomachine.
- [c43] 43.The turbomachinery module of Claim 42, wherein said turbomachinery module has an overall dimension of no greater than 1.75 inches.
- [c44] 44.The turbomachinery module of Claim 42, wherein said turbomachinery module has an overall dimension suitable for 1U applications.

- [c45] 45.The turbomachinery module of Claim 42, wherein said motor comprises magnetic bearings.
- [c46] 46.The turbomachinery module of Claim 42, wherein said compressor comprises at least one of an axial compressor and a centrifugal compressor.
- [c47] 47.The turbomachinery module of Claim 46, wherein said compressor comprises at least one of a single wheel compressor and a multi-wheel compressor.
- [c48] 48.A method for cooling a high power density device, comprising:
drawing air over a heat exchanger using a turbomachine, said heat exchanger being thermally coupled to a high power density device resulting in an increase in air temperature as the air passes over the heat exchanger;
compressing the air at a turbocompressor of the turbomachine having an overall dimension of no greater than 1.75 inches; and
exhausting the heated air to ambient.
- [c49] 49.The method of Claim 48, wherein:
said drawing air comprises drawing air from at least one of an external ambient external to the structure housing the high power density device and an internal ambient internal to the structure housing the high power density device; and
said exhausting the heated air comprises exhausting the heated air to at least one of an external ambient external to the structure housing the high power density device and an internal ambient internal to the structure housing the high power density device.
- [c50] 50.A method for delivering a high flux cooling medium to a high power density device, said method comprising:
compressing a refrigerant at a turbocompressor having an overall dimension of no greater than 1.75 inches;
condensing the refrigerant by removing heat from the refrigerant;
expanding and evaporating the refrigerant to create a cold surface for cooling the high power density device; and
returning the expanded refrigerant to the turbocompressor to repeat the

closed-loop cycle.

- [c51] 51.The method of Claim 50, further comprising a method for delivering low temperature air to cool a high temperature device, said method comprising: generating a first airflow across the condensor using a turbofan; transferring heat from the refrigerant to the first airflow using a heat exchanger; exhausting the heated first airflow to ambient; generating a second airflow across the cold surface of the evaporator using the turbofan; transferring heat from the second airflow to the evaporator using a heat exchanger; and exhausting the chilled second airflow to cool the high temperature device.
- [c52] 52.The method of Claim 51, further comprising: directing a portion of the refrigerant from the compressor to the condensor and another portion from the compressor to an ejector located upstream to the compressor; mixing at the ejector high pressure refrigerant from the compressor with low pressure refrigerant from the evaporator; and delivering the mixed refrigerant to the compressor.
- [c53] 53.The method of Claim 50, wherein said returning the expanded refrigerant to the turbocompressor further comprises: returning the expanded refrigerant via a motor for cooling the motor.
- [c54] 54.A micro turbocompressor for delivering a high flux cooling medium to a device, comprising:
a motor;
a first stage micro compressor disposed at one end of said motor; and
a second stage micro compressor disposed at the other end of said motor.
- [c55] 55.The micro turbocompressor of Claim 54, wherein said first and second stage micro compressors are integral with said motor.
- [c56] 56.The micro turbocompressor of Claim 54, further comprising:
cooling fins disposed on the outer surface of the stator of said motor, said

cooling fins extending from one end of said motor to the other end of said motor, said first stage micro compressor arranged to drive air between said cooling fins, and said second stage micro compressor arranged to draw air between said cooling fins.

[c57] 57. The micro turbocompressor of Claim 56, wherein said cooling fins extend from one end of said motor to the other end of said motor in a nonlinear arrangement.

[c58] 58. A micro turbocompressor for delivering a high flux cooling medium to a device, comprising:
at least one motor; and
a plurality of micro compressors disposed at opposite ends of said at least one motor, said plurality of micro compressors arranged to drive air across the outer surface of at least one stator of said at least one motor.

[c59] 59. The micro turbocompressor of Claim 58, wherein said at least one motor further comprises:
cooling fins disposed on the outer surface of at least one stator of said at least one motor, said cooling fins extending from one end of said at least one motor to the other end of said at least one motor in a nonlinear arrangement.

[c60] 60. A heat exchanger for cooling a high power density device, comprising:
a base for thermally coupling the heat exchanger to the high power density device; and
a plurality of parallel cooling fins arranged perpendicular to said base for receiving driven air at one end and discharging the driven air at the opposite end, said cooling fins having a plurality of concavities.

[c61] 61. A heat exchanger for cooling a high power density device, comprising:
a base for thermally coupling the heat exchanger to the high power density device;
a plurality of parallel cooling fins arranged perpendicular to said base for receiving driven air at one end and discharging the driven air at the opposite end; and

a localized cooling region at said base and between said cooling fins for providing a local region of increased surface area for enhanced heat transfer.

- [c62] 62.A heat exchanger for cooling a high power density device, comprising:
a base for thermally coupling the heat exchanger to the high power density device;
a plurality of parallel cooling fins arranged perpendicular to said base for receiving driven air at one end and discharging the driven air at the opposite end; and
a vortex chamber arranged between said cooling fins for creating a vortex like air flow as the air is driven between said cooling fins and through said vortex chamber.
- [c63] 63.The heat exchanger of Claim 62, wherein said vortex chamber comprises:
first and second sides having first and second ends for receiving and discharging air flow;
said first side having internal ribs arranged oblique to the air flow, a portion of said first side internal ribs being at an angle of positive-beta with respect to the direction of air flow; and
said second side having internal ribs arranged oblique to the air flow, a portion of said second side internal ribs being at an angle of negative-beta with respect to the direction of air flow.
- [c64] 64.The heat exchanger of Claim 63, wherein said first side internal ribs and said second side internal ribs are arranged diagonal to the air flow.
- [c65] 65.The heat exchanger of Claim 63, wherein the first ends of said first and second sides have rounded edges to reduce entry pressure losses at said vortex chamber.
- [c66] 66.The heat exchanger of Claim 63, wherein said first and second sides further comprise first and second edges, said first and second edges being closed and said first edge being thermally coupled to said base.
- [c67] 67.The heat exchanger of Claim 63, wherein said first and second sides further comprise first and second edges, said first edges being open, second edges

being closed, and said first edges arranged proximate to said base.

- [c68] 68.The heat exchanger of Claim 63, wherein said first and second sides are integral with said plurality of parallel cooling fins and further comprise concavities at their side walls.
- [c69] 69.The heat exchanger of claim 63, wherein said first side internal ribs are disposed at an angle of equal to or greater than about 30 degrees and equal to or less than about 120 degrees with respect to said second side internal ribs.
- [c70] 70.The heat exchanger of Claim 63, wherein said beta angle is equal to or greater than about 20 and equal to or less than about 60 degrees.
- [c71] 71.The heat exchanger of Claim 70, wherein said beta angle is equal to or greater than about 40 and equal to or less than about 60 degrees.
- [c72] 72.The heat exchanger of Claim 71, wherein said beta angle is about 45 degrees.
- [c73] 73.A heat exchanger for cooling a high power density device, comprising:
 - a base for thermally coupling the heat exchanger to the high power density device;
 - a plurality of parallel cooling fins arranged perpendicular to said base for receiving driven air at one end and discharging the driven air at the opposite end;
 - a plurality of vortex chambers arranged between said plurality of parallel cooling fins for receiving the driven air at one end and discharging the driven air at the opposite end, said plurality of vortex chambers configured to create a vortex like air flow as the air is driven from said one end to said opposite end; said plurality of vortex chambers having a plurality of first sides, said plurality of first sides having internal ribs arranged oblique to the air flow, a portion of the internal ribs of said plurality of first sides being at an angle of positive-beta with respect to the direction of air flow;
 - said plurality of vortex chambers having a plurality of second sides, said plurality of second sides having internal ribs arranged oblique to the air flow, a portion of the internal ribs of said plurality of second sides being at an angle of

negative-beta with respect to the direction of air flow;
 said plurality of first and second sides further comprising a plurality of first and second edges, said plurality of first edges being open, said plurality of second edges being closed, and said plurality of first edges arranged proximate to said base; and
 a localized cooling region at said base proximate said plurality of first edges for providing a local region of increased surface area for enhanced heat transfer.

- [c74] 74.The heat exchanger of Claim 73, wherein:
 said plurality of parallel cooling fins are integral with said plurality of first and second sides of said plurality of vortex chambers.
- [c75] 75.A method for enhancing the heat transfer characteristic of a heat exchanger for cooling a high power density device, comprising:
 receiving driven air at a first end of a plurality of cooling fins of the heat exchanger;
 driving the air across the plurality of cooling fins for transferring heat from the high power density device to ambient;
 disturbing the air flow as it is driven across the plurality of cooling fins by employing at least one of a plurality of concavities in the plurality of cooling fins, a plurality of localized cooling regions at the base of the heat exchanger and between the plurality of cooling fins, and a plurality of vortex chambers between the plurality of cooling fins for creating a vortex flow between the plurality of cooling fins; and
 discharging the heated air at a second end of the plurality of cooling fins.
- [c76] 76.The method of Claim 75, wherein said creating a vortex flow further comprises:
 creating a vortex flow between the plurality of cooling fins wherein the plurality of cooling fins are integral with the plurality of vortex chambers.
- [c77] 77.The method of Claim 75, further comprising:
 enhancing the heat transfer characteristic of the heat exchanger by at least two-times in comparison to the same heat exchanger absent the plurality of vortex chambers between the plurality of cooling fins for creating a vortex flow

between the plurality of cooling fins.

- [c78] 78. A transition duct for a turbomachinery system, comprising:
a duct housing having a first end with a first flow area for receiving driven air from a heat exchanger having a plurality of cooling fins and a second end with a second flow area for discharging driven air to a turbomachine, said duct housing defining an internal cavity that transitions from said first flow area to said second flow area; and
a plurality of flow control fins within said internal cavity configured to manage the change in flow area from said first flow area to said second flow area.
- [c79] 79. The transition duct of Claim 78, wherein said plurality of flow control fins further comprises:
a plurality of first ends arranged proximate the plurality of cooling fins of the heat exchanger; and
a plurality of second ends extending toward said second end of said transition duct, wherein at least one of said plurality of second ends of said flow control fins does not extend to said second end of said transition duct.
- [c80] 80. The transition duct of Claim 79, wherein said plurality of flow control fins are equal in number to the number of cooling fins of the heat exchanger.
- [c81] 81. A method for transitioning high flux air from a region having a first flow area to a region having a second flow area wherein said first flow area is larger than said second flow area, comprising:
receiving the high flux air at a first end of a transition duct having the first flow area;
segmenting the high flux air flow into separate air flow channels between a plurality of flow control fins;
funneling the high flux air between the flow control fins from the first flow area toward the second flow area; and
discharging the high flux air at a second end of the transition duct having the second flow area.
- [c82] 82. A turbomachinery system for cooling a high power density device,

comprising:

a surface connectible to a high power density device; and
a turbomachine in fluid communication with said surface and configured to
deliver a high flux cooling medium, said turbomachine having a motor and a
compressor driven by said motor.

[c83] 83. The turbomachinery system of Claim 82, wherein said surface comprises at least one of a heat exchanger and a cold plate.

[c84] 84. The turbomachinery system of Claim 83, further comprising a transition duct in fluid communication with said turbomachine and said heat exchanger.

[c85] 85. The turbomachinery system of Claim 84, further wherein said turbomachine is configured to deliver at least one of air and refrigerant.

[c86] 86. The turbomachinery system of Claim 85, wherein said turbomachine has an overall dimension of no greater than 1.75 inches.

[c87]